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A Aljabri
University of Wollongong, ada507@uowmail.edu.au

Z Y. Jiang
University of Wollongong, jiang@uow.edu.au

D B. Wei
University of Wollongong, dwei@uow.edu.au

X D. Wang
Shougang Research Institute of Technology, xiaodong@uow.edu.au

H Tibar
University of Wollongong, hbt796@uowmail.edu.au

Abstract
Strip profile control in cold rolling of thin strip is a difficult and challenge problem found in industry. Currently using the novel type of strip rolling mill, such as the work roll crossing and shifting is the one of the main methods to control the strip profile quality in cold rolling. In this paper, 3-D finite element simulation models of the thin strip profile in cold rolling for the work roll crossing and shifting system were successfully developed. The strip profile and edge drop are discussed considering both crossing angle and shifting value of the work rolls. The research shows that the combination of the work rolls crossing and shifting can effectively improve the strip profile. The developed 3D- finite element model has been verified with the measured values. The obtain result are applicable to control the rolled thin strip profile during cold rolling process.

Keywords
shifting, mill, during, crossing, profile, strip, thin, modeling, cold, rolling, roll

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Modeling of Thin Strip Profile during Cold Rolling on Roll Crossing and Shifting Mill

A.Aljabri[1, a], Z.Y.Jiang[1, b], D.B.Wei[1, c], X.D. Wang[2, d] and H.Tibar[1, e]

[1]School of Mechanical, Materials and Mechtronic Engineering, University of Wollongong, Wollongong NSW 2522, Australia,
[2]Shougang Research Institute of Technology, Shougang, Beijing 100144, China
[a]ada507@uowmail.edu, [b]jiang@uow.edu.au, [c]dwei@uow.edu.au, [d]x_d_wcumt@163.com, [e]hbt796@uowmail.edu.au

Keywords: work roll crossing; work roll shifting; strip shape and profile; thin strip; finite element modeling; cold rolling

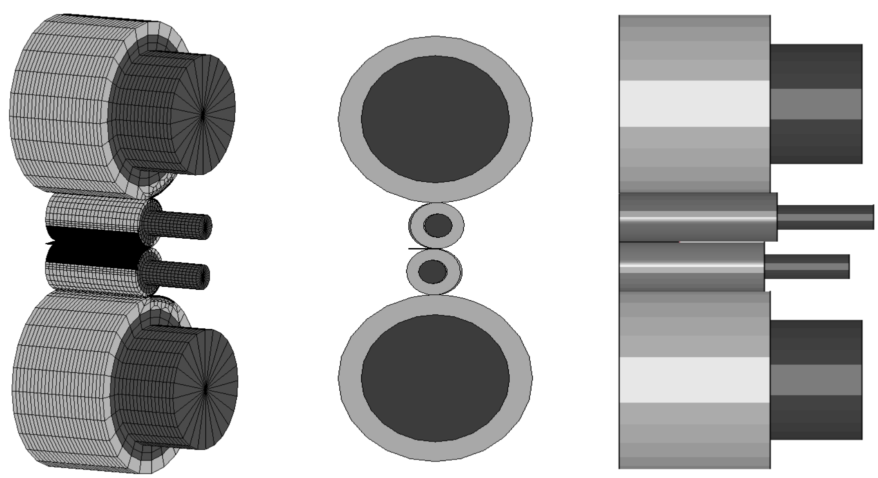
Abstract. Strip profile control in cold rolling of thin strip is a difficult and challenge problem found in industry. Currently using the novel type of strip rolling mill, such as the work roll crossing and shifting is the one of the main methods to control the strip profile quality in cold rolling. In this paper, 3-D finite element simulation models of the thin strip profile in cold rolling for the work roll crossing and shifting system were successfully developed. The strip profile and edge drop are discussed considering both crossing angle and shifting value of the work rolls. The research shows that the combination of the work rolls crossing and shifting can effectively improve the strip profile. The developed 3D- finite element model has been verified with the measured values. The obtain result are applicable to control the rolled thin strip profile during cold rolling process.

Introduction

With the continuous development in science and technology, the requirement of thin strip production has become essential to assess a country's steel manufacturing industry level. In this case an advanced strip shape control is necessary for improving the strip quality that determined by the strip shape. Although these geometric characteristics of the strip have been comprehensively studied by Ginzburg [1] and Robert [2], the market requirements for higher quality and increasingly thinner strip have recently encouraged the development of new technology for producing thinner strip with good shape and flatness. In fact, the strip shape control naturally is to improve the strip profile using advanced technologies. Therefore, it is necessary to study the factors affecting the strip profile in cold rolling. At present, the advanced control shape rolling mills, such as the continuous variable crown (CVC) and pair cross (PC) [3] and the work rolls crossing and shifting (RCS) [4] mills have been developed to improve the strip shape and profile. These rolling mills with excellent strip shape control characteristics have been used widely in cold strip rolling. Over the past investigators found that these advanced rolling mills are appropriate to control the strip shape, profile and flatness when the rolling process is applied to the rolling of thick strip, and the control of the strip shape, profile and flatness no longer present a serious challenge to rolling mill operation for relatively thick products [5-9]. However, until now, the roll-strip model of the work roll crossing and shifting mill in cold rolling for thinner gage strip is still a challenge in rolling practice, this involves the control of the strip dimensional accuracy and the strip crown. Thus, a major work for steel's researchers and manufacturers is to introduce finite element analysis of the strip shape performance in cold rolling of thin strip. Previous researchers have investigated strip shape and profile [9-12]. In this work, a 3-D finite element modeling of the strip shape during cold rolling of thin strip in the work roll crossing and shifting mill has been carried out using the explicit dynamic expression of elastic- plastic code. In order to enhance the analysis accuracy of the strip profile model simulation results are compared, and verified with the measured value.

Finite Element Model for Analysis of Thin Strip Profile

A 3D non-linear finite element model has been developed to simulate the thin strip of cold rolling with work roll crossing and shifting mill. Due to symmetry, the simulation process involves of a roll system along the roll barrel (see Figure 1(a) and (c)). Fig.1 (a), Fig.1 (b) and Fig.1 (c) show the detail views the geometry of the work rolls crossing and shifting (WCS) when the cross angle and shifting value used. The geometric parameters and physical properties of the model are shown in Table 1 and Table 2 shown. In this model, the roll materials were regarded as elastic materials while the strip material was regarded as elastic-plastic material. The element of eight-node, isoperimetric, arbitrary hexahedral was used for the strip and rolls. The Update Lagrange method and large deformation method were used. Moreover, only the possible contact areas were meshed very fine.



(a) (b) (c)

Figure 1 3D FE model to simulate the work rolls crossing and shifting rolling mill

Table 1 Geometric parameters of the model

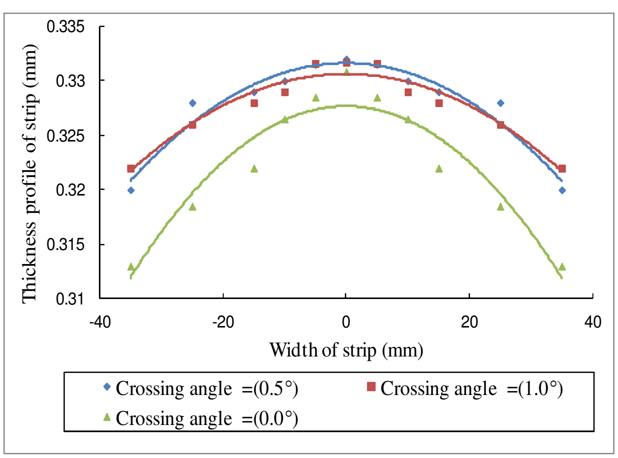
	Parameters	Value
Backup roll	Roll diameter, mm	228
	Roll face length, mm	250
Roll system	Roll diameter, mm	63
	Roll face length, mm	250
Strip	Entry thickness, mm	0.550
	Exit thickness, mm	0.330

Table 2 Physical property of the model

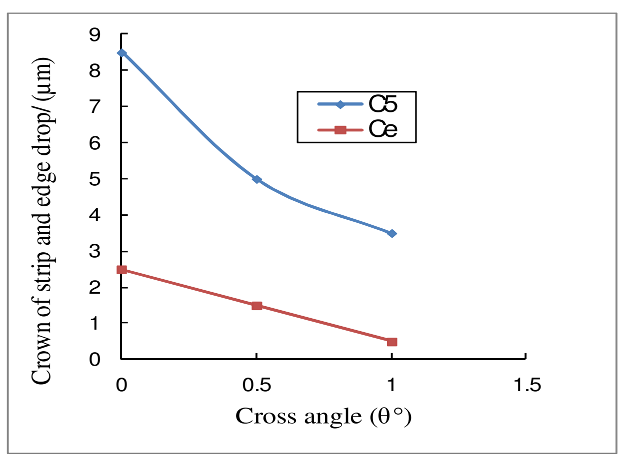
	Parameters	Value
Strip	Young's modulus, MPa	205000
	Poisson ratio	0.27
	Density, Kg/m^3	7.85×10^3
	Yield stress, MPa	$\sigma = 160.33$
Roll system	Young's modulus, MPa	210000
	Poisson ratio	0.3
	Density, Kg/m^3	7.85×10^3

Results and discussion

Effect of crossing angle on the strip profile. Fig.2 (a) and (b) shows the exit strip profiles under different work roll crossing angles and without work roll shifting with strip width of 80 mm. As shown in Fig.5, the strip thickness did not differ significantly, but when the crossing angle was zero, it decreased dramatically towards the strip edge which resulting in increase of the strip crown. The great variation of thickness near the strip edges was attributed to the fact that the resistance of transverse flowing in the area near the strip edges was relatively low and this reflects the character of the general strip profile produced with conventional rolling mill. Whilst with the increase of roll crossing angle, the strip profiles were more flat, which prove that the work roll crossing system has the ability to adapt the roll gape profile causing the roll gap distribution to be uniform. This action leads to obtain large efficiency of shape and profile control. In order to illustrate it more clearly, the metric of crown and edge drop were used to estimate the strip profile. Here, the strip crown C_5 was defined as the variation value between the thickness at the strip center and the thickness at a 5mm distance from the edge, and the edge drop C_e was defined as the variation value between the thickness at 35mm distance from the strip edge, and the thickness at the 10mm distance from the strip edge. Fig.2 (b) shows the effect of the roll crossing angle on C_5 and C_e. It can be seen that both C_5 and C_e decreased with an increase of the roll cross angle, which was attributed to the fact that the transverse flowing of the metal was controlled with crossing angle.



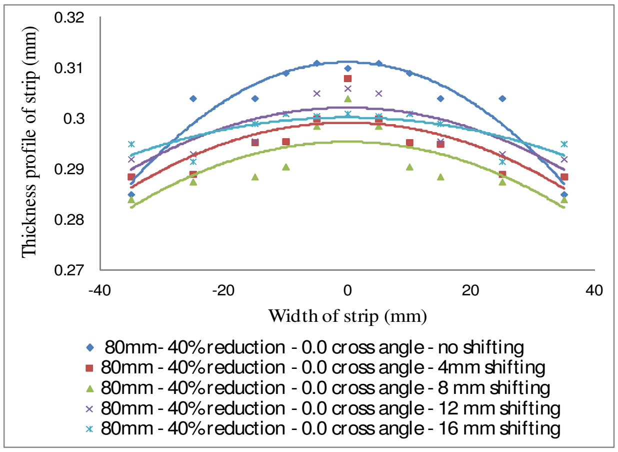
(a)

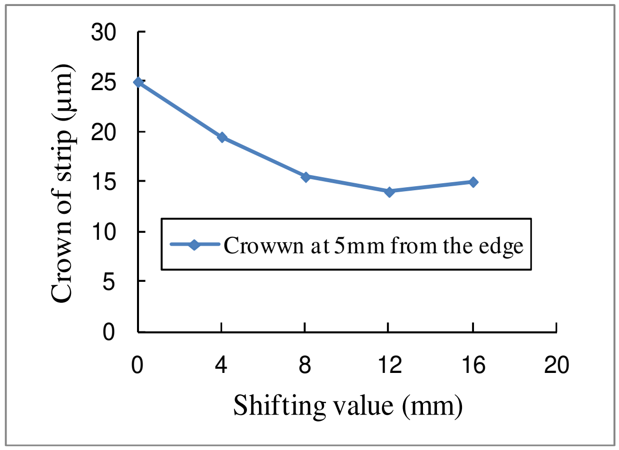


(b)

Figure 2. (a) Effect of cross angle on the strip profile, (b) Effect of cross angle on the strip crown and edge drop.

Effect of the work roll shifting on strip profile. Fig.3 (a) and (b) show the exit strip profiles and its crown under different work roll shifting values and without crossing angle with strip width of 80 mm. It is obvious that the shape control ability of roll shifting is much less than that of rolls crossing. However, the strip profile improves obviously when the shifting value increases as shown in Fig.3 (a). This indicates that when the top work roll shifts to the left and the bottom work roll shifts the same amount to the right, the force distribution between rolls changes. This reaction affects the forces over the strip and makes them more uniform, which lead to increase the strip crown control range as shown in Fig.3 (b) and to avoid asymmetrical roll wear.





(a) (b)

Figure 3. (a) Effect of the work roll shifting on strip profile, (b) Effect of the work roll shifting on strip crown

Effect of the combination of the work rolls crossing and shifting on strip profile. Since the work roll crossing and shifting rolling mill used as a multiple shape control systems provide an easy and relatively inexpensive way to provide high efficiency profile control devices, which avoid or minimise the formation of wear caused by worn rolls, by axial shifting of the work rolls, and reduces the strip crown and edge drop by implanting work roll crossing rolling system. Fig. 4 shows the influence of the work rolls crossing and shifting on strip profile. It can be seen that the strip profile changes toward flat shape when changing the work roll axial shifting value at a cross angle of 0.5°. This could be a result of modifying the roll gap profile by crossing angle and simultaneously the local roll wear decreases as the shift amount of roll stroke increases.

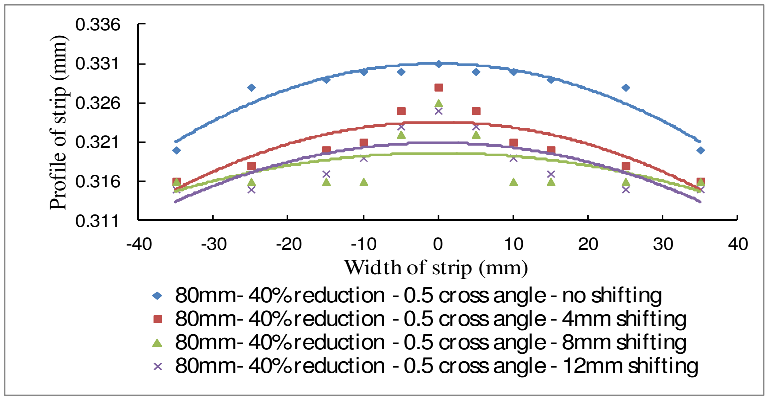


Figure 4. Effect of the work rolls crossing and shifting on strip profile.

In order to verify the finite element of strip profile analysis, extensive tests were carried out on a 4-high Hille 100 rolling mill revamped for the purpose of research with a work roll crossing and shifting system. The specification for the test mill is given in Table 3.

Table 3 Specification for 4-high Hille 100 rolling

Mill system	Work roll crossing and shifting
Cross angle	0-1.5°
Shifting value	0-16 mm
Work roll	Diameter = 63 mm, length = 250 mm
Backup roll	Diameter = 228mm, length = 250 mm
Rolling force	0-1500 kN
Rolling torque	0-13 kN m
Rolling speed	0-60 rpm

Fig. 5 shows the measured exit thickness along the strip width during cold rolling of thin strip with the work roll crossing and shifting system. In order to verify the validity of the finite element modeling of strip profile, a comparison of the simulated strip profile with the measured values has been conducted, as shown in Figs.6. It can be seen that the simulation results are closed to the measured values. Therefore, the simulation of the thin cold strip rolling by FEM can predict the distribution of strip profile along the strip width accurately.

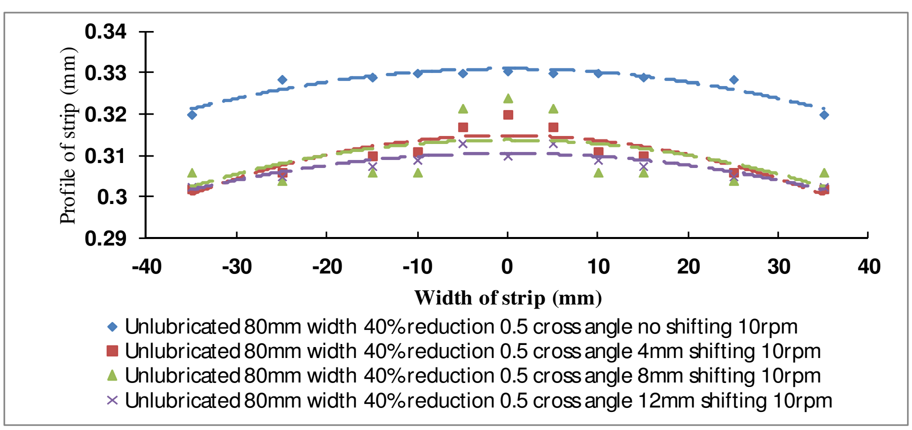


Figure 5. Thickness distribution at various work rolls crossing and shifting values

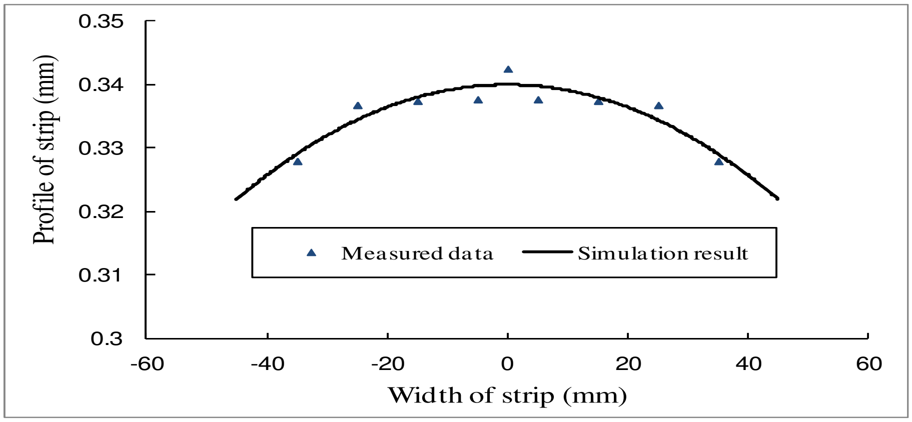


Figure 6. Comparison of calculated strip thickness with measured value

Conclusions

The exit strip profile for thin strip in cold rolling process was numerically estimated considering the work roll crossing, axial work roll shifting and the combination of the work rolls crossing and shifting using elastic-plastic finite element method code. The following conclusion may be drawn from the results of this study.

1. The strip profile is improved as the crossing angle increased.
2. Under the same condition, the exit strip crown and/or edge drop would decreases as the roll crossing angle increases.
3. The axial roll shifting changed both the strip profile distribution over the strip width and the strip edge shape. This may be as a result of the redistribution of roll wear along the strip width.
4. The practical application has demonstrated that the combination of the work rolls crossing and shifting can effectively improve the strip profile.
5. The result of strip profile control capabilities of this rolling mill will serve as a useful reference for building a thin strip shape control model and choosing other types of cold strip rolling mills.
6. Using the dynamic explicit expression of elastic-plastic FEM, a computational model for the work rolls crossing and shifting cold rolling mill is established which demonstrates its reliability by comparing results with measured values.
7. The numerical simulation can provide theoretical basis for the model of controlling strip profile in thin strip rolling process.

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